Structural Dynamics . . .

LEGACY REPRINT:

Hard Hats for the Weapon Systems

by Capt Wallace E. Fluhr

Editors Note: This article was originally published in the February 1961 issue of the Air Force Civil Engineer *Magazine. It is offered here as an example of the professional/technical articles from the publication's early years and also as a reminder of the challenges civil engineers confronted in the early 1960s as they became involved in the ICBM program.*

The successful design of underground structures capable of surviving a near miss from a nuclear explosion requires a knowledge of the loads that are imposed upon these structures. It has been the responsibility of the Office of the Deputy Commander, Civil Engineering, Air Force Ballistic Missle Division (ARDC) to determine these loads and to design our underground missile facilities.

Figure 1 represents schematically a silo for missile launching which is to survive the effects of a surface nuclear detonation. Immediately below the point of detonation, the earth is subjected to a tremendous applied pressure. This suddenly applied pressure results in thea formation of a wide, shallow crater and the shock propagates through the soil as various types of waves. These waves are called the direct ground transmitted shock. Radiating outward from the burst center is a high-intensity pressure pulse in the air above the surface. This is called the air blast wave and measured as overpressure. Near the burst, the pressure in this air wave is of the order of thousands of pounds per square inch; however, its pressure decays as the pressure pulse moves out over the earth.

Capt Fluhr received his BS in Civil Engineering from the University of Kentucky in 1954. Called to active duty in 1954, he was assigned to the BE office at Gunter AFB, Alabama. Under the Air Force Institute of Technology program, he began graduate education at the University of Illinois in 1957. Majoring in Structural Dynamics, he received his MS in Civil Engineering in 1959, and in June, 1960, he completed his Doctorate in the same field. Upon completion of graduate work, he was assigned to the Office of the Deputy Commander, AFBMD. He is a registered professional engineer in Kentucky, a member of ASCE and the American Concrete Institute.

As the air pressure pulse moves away from the center of the burst, it slaps the earth which in turn generates shock waves in the earth which propagate in all directions. The character of these air induced waves depends on the velocity, magnitude and duration of the pressure pulse and the density, stiffness, damping and stratification of the earth medium. Thus, the type of disturbance at an underground launch site is likely to be complicated since it represents the effects of waves generated in different ways and passing through complicated and nonhomogeneous earth media.

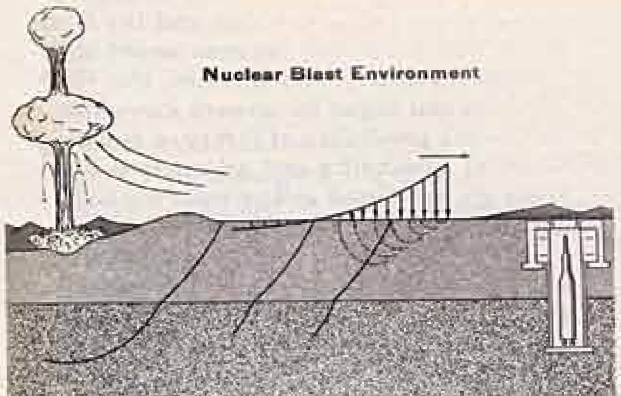
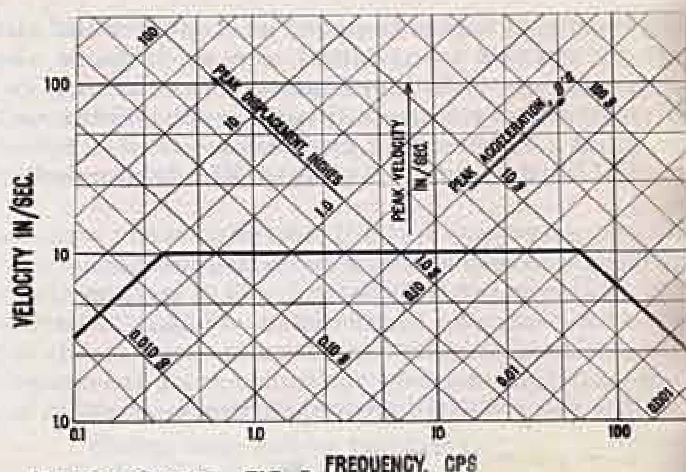


FIG. 1

The major function of the silo-type launcher is to protect the missile from enemy attack. Not only does the underground launcher resist the normal earth loading on the launcher, but it must resist the loading caused by the passing of the air blast wave which in turn applies additional pressures and ground motions to the launcher. These ground motions (ground shock) are transmitted directly to the silo structure and its response is in turn transmitted to the missile and equipment inside. Unless special means of shock isolation are provided, the response of the missile and equipment to the shock could cause loads high enough to cause structural failure. Therefore, the missile and the important equipment are suspended on soft springs or other shock isolation devices which in effect allow the silo structure to move around them. It is extremely important that Air Force civil engineers understand the principles of shock isolation since it will be our job to maintain the ICBM facilities.

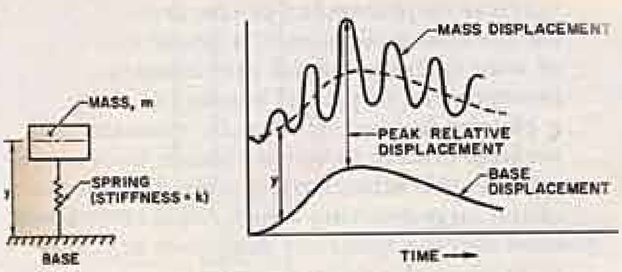
Consider the simple oscillator shown in Figure 2, consisting of a mass m (corresponding to the missile or equipment) attached by a linear spring of spring constant k (corresponding to the shock isolation device) to the base. Figure 2 also illustrates the displacement responses for this system for one value of natural frequency of the oscillator and for the given input displacement of the base. The natural frequency of the oscillator, of course, depends only on the properties of the system, that is, the mass m and the spring constant k. It is convenient to discuss the behavior of a simple oscillator system in terms of the maximum response of the system plotted as a function of its natural frequency. A plot of this nature is called a response spectrum. There are three types of response spectra: displacement, velocity and acceleration. By means of a logarithmic plot, as shown in Figure 3, the response spectrum can be represented by three regions of a single plot, each region defined by a straight line constituting an envelope to the actual spectrum. Briefly then, response spectra show, for a single-degree-of-freedom system, the peak response of the system relative to the ground motions as a function of the natural frequency of the single-degree-of-freedom system. Such spectra are applicable directly to elastic systems if their frequency, their type and mode of support are known.

For more complex isolation systems, such as non-linear systems and multi-degree-of-freedom systems, the analysis is more difficult and involves a solution of the equations of motion of the system in which the characteristics of stiffness, mass and damping distributions of the system, along with the shock pulse input, are suitably taken into account.



Response Spectra FIG. 3

Air Force civil engineers who are now or will soon be charged with the responsibility of maintaining our missile facilities should be on guard against any modifications to the shock isolation systems. All systems and equipment have been thoroughly analyzed in the design phase for their dynamic response to shock inputs. These analyses have, in some cases, been very complex but, in all cases, these analyses have been thorough. Therefore, complete appreciation of the change in response that can occur due to a change in the mass of the isolated system or a change in spring stiffness must be had by all. No operational modification should be made to any part of the missile facilities without a thorough dynamic analysis to determine the response from shock inputs.



Displacement Response of Single Degree of Freedom System FIG. 2